NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2469

RUPTURE PROPERTIES OF LOW-CARBON N-155 TYPE ALLOYS MADE WITH A COLUMBIUM-TANTALUM FERRO-ALLOY

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SUMMARY

An experimental columbium-tantalum ferro-alloy (40Cb-20Ta) was used to make laboratory heats of low-carbon N-155 and an N-155 type alloy (20Cr-20Ni-20Co+2Cb). The amount of columbium in the alloys was reduced so as to keep the atomic percent of columbium plus tantalum equal to the normal atomic percent of columbium. Rupture tests at 1200° and 1500° F on forged and heat-treated bar stock did not show a significant change from the resulting presence of tantalum in the alloys.

This limited investigation therefore indicates that the use of high-tantalum ferro-columbium would be satisfactory for making heat-resisting alloy of these types. An actual saving in columbium as well as the utilization of columbium not otherwise available would result.

INTRODUCTION

Tantalum occurs together with columbium in certain ores in a manner which makes their separation impractical. Such ores, however, could be utilized to produce practical columbium-tantalum ferro-alloys. The effect of a high content of tantalum in ferro-columbium on the properties of columbium-bearing alloys has not, however, been established. If satisfactory alloys could be made with columbium-tantalum ferro-alloys, particularly if tantalum could be substituted for part of the columbium, the amount of columbium available would be considerably increased. Inasmuch as columbium is used to a considerable extent in heat-resistant alloys for jet engines, it was considered important to investigate the effect of tantalum on the properties of such alloys at high temperatures.

Because low-carbon N-155 alloy had been extensively studied by the University of Michigan in their research programs on heat-resistant alloys for the National Advisory Committee for Aeronautics, it was decided to study the effect of using an experimental columbium-tantalum ferro-alloy in making this alloy. The ferro-alloy used had a tantalum to columbium ratio of 0.55. In addition to low-carbon N-155 alloy, the ferro-alloy was also used to prepare a heat of a type N-155 alloy (20Cr-20Ni-20Co+2Cb). Because this latter alloy did not contain molybdenum or tungsten it was thought that any effects of the tantalum might be intensified and made more evident.

In such alloys, tantalum in many respects has metallurgical characteristics similar to those of columbium. For this reason, the experimental alloys were made with the amount of the columbium-tantalum ferro-alloy needed to yield the same atomic percent of columbium plus tantalum as the atomic percent of columbium in the unmodified alloys. This procedure reduced the amount of columbium used.

Rupture test properties at 1200° and 1500° F were the major basis of evaluation of the effect of using the columbium-tantalum ferro-alloy. Comparative data at 1200° F were available for the unmodified alloys in reference 1. Unpublished data were used for comparison at 1500° F. Both types of alloys were made with a procedure carefully controlled to minimize all variables except chemical composition. (See reference 1.)

This investigation was conducted under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics as part of a program of research on heat-resistant metals at the Engineering Research Institute of the University of Michigan.

TEST MATERIALS

The tantalum-modified alloys were prepared by induction melting 9-pound heats, deoxidizing with 15 grams of calcium-silicon alloy, and casting into a 9-inch-long tapered $\left(1\frac{5}{8}\text{- to }1\frac{1}{4}\text{-in.-square}\right)$ ingot. The ingots were hammer-forged with a 400-pound air hammer between swaging dies to 0.45-inch round bar stock. The initial forging temperature was 2200° F with a finishing temperature above 1800° F, as judged by color. The bar stock was solution-treated 1 hour at 2200° F, water-quenched, and aged 24 hours at 1400° F before testing. This procedure, the details of which are described in reference 1, was the same as that used for preparing the unmodified columbium-bearing alloys.

The chemical analyses of the two tantalum-modified alloys, together with those of the unmodified alloys, were:

Alloy	Heat	Chemical composition (percent)										
		C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Ta	N
Unmodified low-carbon N-155	(a)	0.15	1.5	0.5	20.0	20.0	20.0	3.0	2.0	1.0	0	0.14
	8	.14	1.46	.41	21.17	20.16	19.81	3.03	2.08	0.96	----	.14
	10	.15	1.40	.52	20.89	20.64	19.30	3.05	1.91	1.03	----	.17
	12	.16	1.61	.67	21.04	18.39	22.00	3.03	2.01	1.15	----	.14
	27	.15	[b]1.7	.58	[b]20	[b]20	[b]20	[b]3	[b]2	[b]1	----	[b].14
Ta-modified low-carbon N-155	85	0.15	[b]1.7	[b]0.5	[b]20	[b]20	[b]20	[b]3	[b]2	0.78	[c]0.44	[b]0.14
Unmodified 20Cr-20Ni-20Co+2Cb	68	0.18	[b]1.7	[b]0.5	[b]20	[b]20	[b]20	0	0	1.81	----	[b]0.14
Ta-modified 20Cr-20Ni-20Co+2Cb	78	0.15	[b]1.7	[b]0.5	[b]20	[b]20	[b]20	[b]0	[b]0	1.19	[c]0.65	[b]0.14

[a]Nominal composition for unmodified low-carbon N-155.

[b]Actual chemical analyses were not made but aim analyses are given.

[c]Chemical analyses were made for columbium plus tantalum, the ratio of columbium to tantalum in the alloy being assumed to be the same as in the columbium-tantalum ferro-alloy. (This assumption probably leads to high values for tantalum because its loss during melting is generally higher than for columbium.)

The ferro-alloy contained 39 percent columbium and 21 percent tantalum and was furnished by the Electro Metallurgical Division of Union Carbide and Carbon Corporation. The amount added to the heats was intended to give the same atomic percentage of columbium plus tantalum as columbium alone in the unmodified alloys. The columbium equivalent of heat 85 was 1.00 weight percent and of heat 78 was 1.53 weight percent. The latter alloy, therefore, had less columbium plus tantalum than the aim atomic equivalent of 2 percent columbium.

The high-temperature load-carrying ability of the alloys was evaluated by means of stress-rupture tests to establish 100-hour strengths at 1200° and 1500° F. The tests were of sufficient number and duration to permit reasonably reliable extrapolation of 1000-hour strengths. Rupture test specimens were 0.250 inch in diameter with a 1-inch gage length. The stress-rupture tests were made in individual stationary units, applying the load by a simple beam acting through a system of knife edges. Time-elongation data were taken during the tests by the drop-of-the-beam method.

Metallographic examinations were made of the alloys in as-cast, hot-forged, solution-treated, aged, and rupture-tested conditions. Vickers hardness tests were made on bar stock in the solution-treated and the aged conditions.

RESULTS AND DISCUSSION

Rupture test data for the two tantalum-modified alloys at 1200° and 1500° F are given in table I. The stress and rupture-time curves are plotted in figure 1. The stress and minimum-creep-rate data from time-elongation curves obtained during rupture testing are plotted in figure 2. The data for the unmodified alloys included in these two figures were taken from reference 1 and from an unpublished investigation. In table II the rupture strengths, elongations, and stresses at constant creep rates of the modified alloys are compared with those of the unmodified alloys.

The rupture strengths, elongation, and stresses at constant creep rates of the tantalum-modified low-carbon N-155 alloy (heat 85) were only slightly above or within the property range of the four heats of unmodified low-carbon N-155 at both 1200° and 1500° F.

The strength properties of the tantalum-modified N-155 type alloy (heat 78) as compared with those of the unmodified alloy (heat 68) were approximately 2000 psi lower at 1200° F and 2000 psi higher at 1500° F. The elongation of the tantalum-modified alloy in the rupture test may have been significantly lower than the unmodified alloy at 1200° F and higher at 1500° F, although the data for the one heat of unmodified alloy are too few to be certain.

The four heats of the unmodified low-carbon N-155 alloy were originally used to determine the degree to which the properties of this alloy could be reproduced under the experimental conditions and were prepared in a manner which was believed to have minimized the effects of variables in processing on high-temperature properties. The ranges in strength properties of these heats were 2000 psi or less at both 1200° and 1500° F. Since the difference that did exist between the two types of tantalum-modified and the unmodified alloys was only 2500 psi or less, it can be concluded that the substitution of tantalum for part of the columbium in these two alloys did not significantly alter the high-temperature rupture strengths up to 1000 hours. There was a slight indication that the tantalum-modified alloys would have improved long-time rupture strength at 1500° F because the slopes of their stress and rupture-time curves were less than those for the unmodified alloys.

The forging characteristics of the alloys made with the columbium-tantalum ferro-alloy were similar to those of the unmodified alloys. This observation, while based on quite qualitative observations, should be fairly reliable because it was based on the experience gained in forging over a hundred heats of alloys of this type.

The following tabulation indicates that there was no significant hardness difference as the result of the addition of tantalum:

Alloy	Heat	Vickers hardness number	
		Solution-treated	Solution-treated and aged
Ta-modified low-carbon N-155	85	229	252
Unmodified low-carbon N-155	8 10 12 27	229 234 224 211	247 259 243 221
Ta-modified 20Cr-20Ni-20Co+2Cb	78	196	199
Unmodified 20Cr-20Ni-20Co+2Cb	68	196	201

There was likewise no significant difference between the microstructures of the unmodified and the tantalum-modified alloys. Photomicrographs were therefore not included in this report.

It was shown in reference 1 that the addition of columbium in excess of 1 percent to these type alloys had little or no influence on rupture strengths at 1200° F. It was also suggested that columbium in amounts lower than 1 percent might yield rupture strengths comparable with those of alloys containing 1 percent columbium. Thus it may have been that the 0.78 percent columbium in the tantalum-modified low-carbon N-155 alloy (heat 85) was sufficient to give the same rupture properties as the unmodified alloy containing 1 percent columbium. A similar situation probably exists for the alloy with molybdenum and tungsten omitted. It therefore may be that both alloys had sufficient columbium alone to provide the strengths obtained and, because of the saturation effect, the tantalum had only a minor effect.

In addition to using columbium not otherwise available, the use of the columbium-tantalum ferro-alloy resulted in an actual reduction of the amount of columbium used. The tantalum-modified low-carbon N-155 alloy contained 22 percent less columbium than the unmodified alloy without sacrifice in properties.

CONCLUSIONS

An experimental columbium-tantalum ferro-alloy was substituted for ferro-columbium in making small laboratory heats of low-carbon N-155 alloy and an N-155 type alloy (20Cr-20Ni-20Co+2Cb) without significantly changing rupture properties of either alloy at 1200° and 1500° F. Other characteristics of the alloys were also similar.

The results of this limited investigation therefore support the probable practicality of using high-tantalum ferro-columbium for making columbium-bearing heat-resistant alloys. Reduced columbium requirements, as well as the feasibility of utilizing high-tantalum columbium ores, is indicated inasmuch as the columbium plus tantalum in the ferro-alloy (40Cb-20Ta) was substituted for columbium in the alloys on an atomic percentage basis with no evident adverse effect.

University of Michigan
Ann Arbor, Mich., April 14, 1950

REFERENCE

1. Reynolds, E. E., Freeman, J. W., and White, A. E.: Investigation of Influence of Chemical Composition on Forged Modified Low-Carbon N-155 Alloys in Solution-Treated and Aged Condition as Related to Rupture Properties at 1200° F. NACA TN 2449.

TABLE I.- RUPTURE TEST DATA FOR TANTALUM-MODIFIED LOW-CARBON N-155 TYPE ALLOYS

Alloy	Test temperature (°F)	Stress (psi)	Time for rupture (psi)	Elongation in 1 in. (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
Ta-modified low-carbon N-155 (heat 85)	1200	53,000	79	24	24.8	0.124
		50,000	85	17	18.3	-----
		48,000	175	16	21.8	.069
		45,000	249	28	28.2	.040
	1500	18,000	80	34	38.4	-----
		16,500	180	34	29.5	0.039
		15,000	376	26	33.8	.020
Ta-modified 20Cr-20Ni-20Co+2Cb (heat 78)	1200	40,000	47	23	25.4	-----
		35,000	174	25	21.8	0.069
		32,500	399	24	22.6	.022
	1500	16,000	47	53	47.5	-----
		15,000	66	44	44.2	-----
		13,000	176	28	34.0	0.059
		11,000	585	26	32.7	.011
		10,000	1670	19	23.4	.0047

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TABLE II.- COMPARATIVE RUPTURE TEST CHARACTERISTICS OF TANTALUM-MODIFIED AND UNMODIFIED LOW-CARBON N-155 TYPE ALLOYS

Alloy	Temperature (°F)	Heat	Rupture strength (psi)		Estimated 100-hr rupture elongation in 1 in. (percent)	Stress required to cause indicated creep rates (psi)	
			100 hr	1000 hr		0.01 percent/hr	0.1 percent/hr
Ta-modified low-carbon N-155	1200	85	50,000	[a]38,000	20	[a]37,000	50,500
[b]Unmodified low-carbon N-155	1200	8	48,500	37,000	22	35,800	47,500
		10	50,000	38,000	19	35,400	49,000
		12	50,000	[a]38,000	27	------	48,500
		27	48,000	37,000	25	37,000	46,200
			[c]49,125	[c]37,500	[c]23	[c]36,100	[c]47,800
Ta-modified low-carbon N-155	1500	85	17,500	[a]13,400	34	13,600	[a]18,200
[b]Unmodified low-carbon N-155	1500	8	16,500	11,800	16	13,400	[a]18,000
		10	18,500	12,900	30	15,000	18,100
		12	17,100	11,900	30	13,900	17,000
		27	16,500	12,000	32	12,800	16,400
			[c]17,150	[c]12,150	[c]27	[c]13,775	[c]17,375
Ta-modified 20Cr-20Ni-20Co+2Cb	1200	78	37,500	[a]30,000	25	31,000	36,000
[b]Unmodified 20Cr-20Ni-20Co+2Cb	1200	68	40,000	[a]32,000	35	[a]31,500	38,000
Ta-modified 20Cr-20Ni-20Co+2Cb	1500	78	14,100	10,400	42	10,700	13,700
[b]Unmodified 20Cr-20Ni-20Co+2Cb	1500	68	12,500	[a]8,500	30	8,900	12,000

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[a]Estimated.
[b]Date obtained from reference 1 and an unpublished investigation.
[c]Average value.

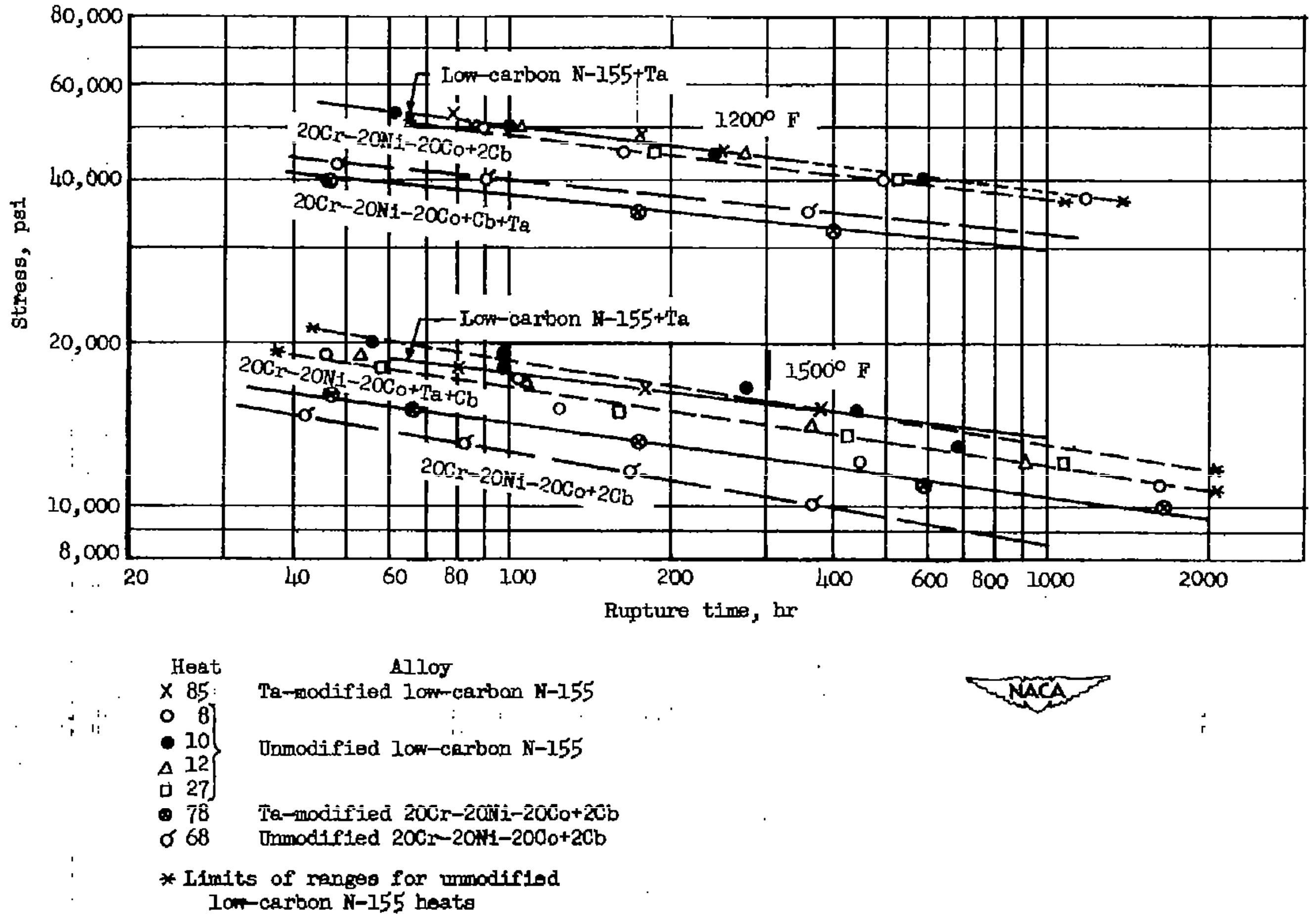
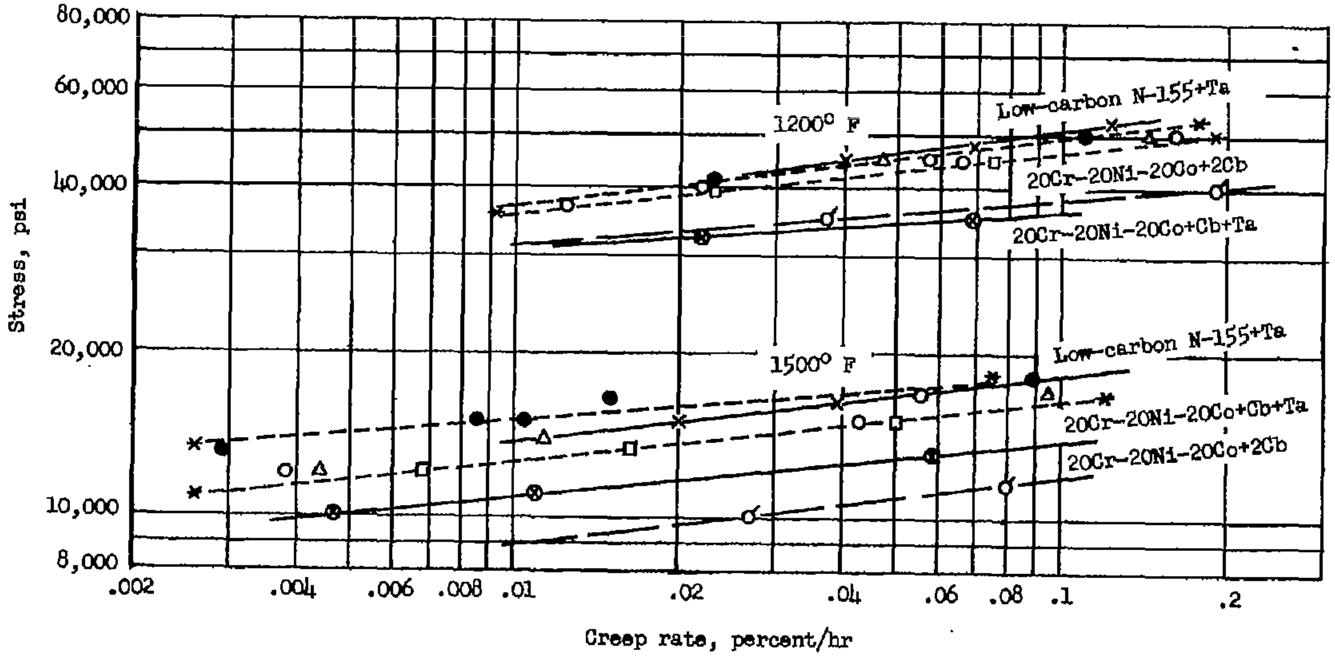


Figure 1.- Curves of stress against time for rupture at 1200° and 1500° F for unmodified and tantalum-modified low-carbon N-155 and an N-155 type alloy (20Cr-20Ni-20Co+2Cb). All alloys were solution-treated at 2200° F for 1 hour, water-quenched, and aged at 1400° F for 24 hours. Data for unmodified alloys were obtained from reference 1 and an unpublished investigation.



Heat	Alloy
× 85	Ta-modified low-carbon N-155
○ 8	Unmodified low-carbon N-155
● 10	Unmodified low-carbon N-155
△ 12	Unmodified low-carbon N-155
□ 27	Unmodified low-carbon N-155
⊗ 78	Ta-modified 20Cr-20Ni-20Co+2Cb
♂ 68	Unmodified 20Cr-20Ni-20Co+2Cb

*Limits of ranges for unmodified low-carbon N-155 heats

Figure 2.- Curves of stress against minimum creep rates at 1200° and 1500° F for unmodified and tantalum-modified low-carbon N-155 and an N-155 type alloy (20Cr-20Ni-20Co+2Cb). All alloys were solution-treated at 2200° F for 1 hour, water-quenched, and aged at 1400° F for 24 hours. Data for unmodified alloys were obtained from reference 1 and an unpublished investigation.

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